3-Phase BLDC/PMSM Low Voltage Power Stage User Guide

Devices Supported:
MC33937A

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freescale

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About This Book

This document describes the 3-Phase BLDC/PMSM Low Voltage Power Stage, targeted for rapid development of motor control applications.

To locate any published updates for this document, refer to the Freescale websaite at: http://www.freescale.com/.

Revision History

Table i. Revision History

Date	Revision level	Description	Page number(s)
08/2012	0	Initial release	30

Documentation

The MC33937A documentation is available at the Freescale web site, http://www.freescale.com. as follows:

- Data sheet — MC33937A modules in detail
- Product briefs — device overview
- Application notes — address specific design issues

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Chapter 1 Introduction

Freescale's embedded motion control series 3-Phase BLDC/PMSM Low Voltage Power Stage is an 8 V–50 V, 10 Amps, surface-mounted power stage. In combination with one of the embedded motion control series controller boards, it provides a software development platform that allows algorithms to be written and tested without the need to design and build a power stage. It supports speed and position sensing based on Hall sensors, resolver sensors, encoder sensors, and back electromotive force (BackEMF) signals for sensorless control.

The 3-Phase BLDC/PMSM Low Voltage Power Stage has an over-current protection. It is independent of the control board when you choose the internal MC33937A DC bus operational amplifier with an over-current comparator. You must therefore be careful when you drive low impedance motors. The current measuring circuitry is setup for ±10 Amps full scale. At ambient temperature (25 °C), the board remains within thermal limits when operating with output currents of up to 10 Amps continuous RMS.

Input connections are made via the 40-pin and 10-pin ribbon cable connectors J3 and J4. Pin assignments for the input connector are illustrated in Section 2.2, "UNI3 Interface J3." Power connections to the motor are made on the 3-way connectors J6 (Phase A), J7 (Phase B), and J8 (Phase C). The input voltage requirements are met by a power supply of 8 V–50 V. The voltage should be within these limits. The board sustains a voltage of at least 8 V with a maximum of 58 V. The input power is supplied by means of the 2.1 mm jack connector J2 or clamp connector J1.

The following is summary of the information required to use the 3-Phase BLDC/PMSM Low Voltage. For design information, see Section Chapter 3, "Design Consideration."

1.1 Features

The 3-phase low voltage power stage features are:

- MC33937A MOSFET pre-driver
- Motor control interface:
  - UNI-3
  - MC33937A pre-driver
- Braking chopper circuit
- Phase and DC-Bus voltage and current sensing circuits
- DC-Bus over current protection
- +12 Vdc, +5 Vdc DC-DC converters

1.2 Board architecture

The 3-phase low voltage power stage contains basic building blocks. See Figure 1-1.

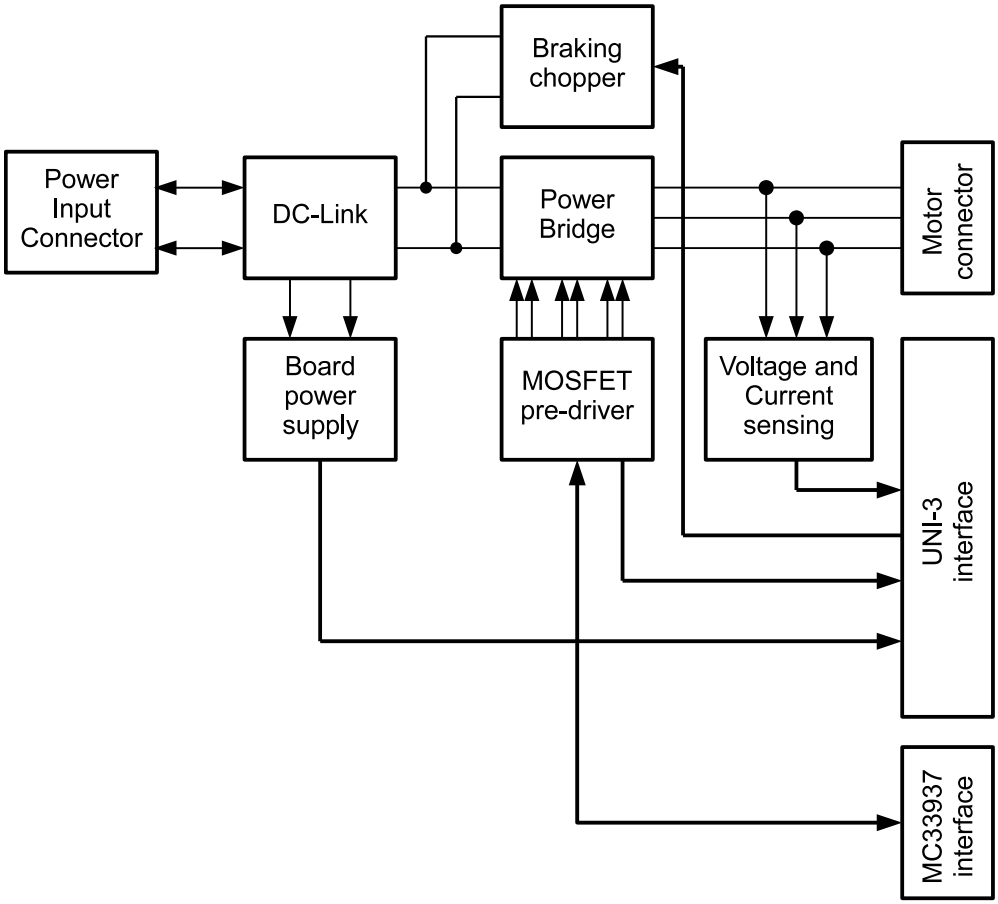

Figure 1-1. 3-Phase BLDC/PMSM Low Voltage Power Stage controller board block diagram

The board is supplied by VBAT voltage in the range of 8 V–50 V.

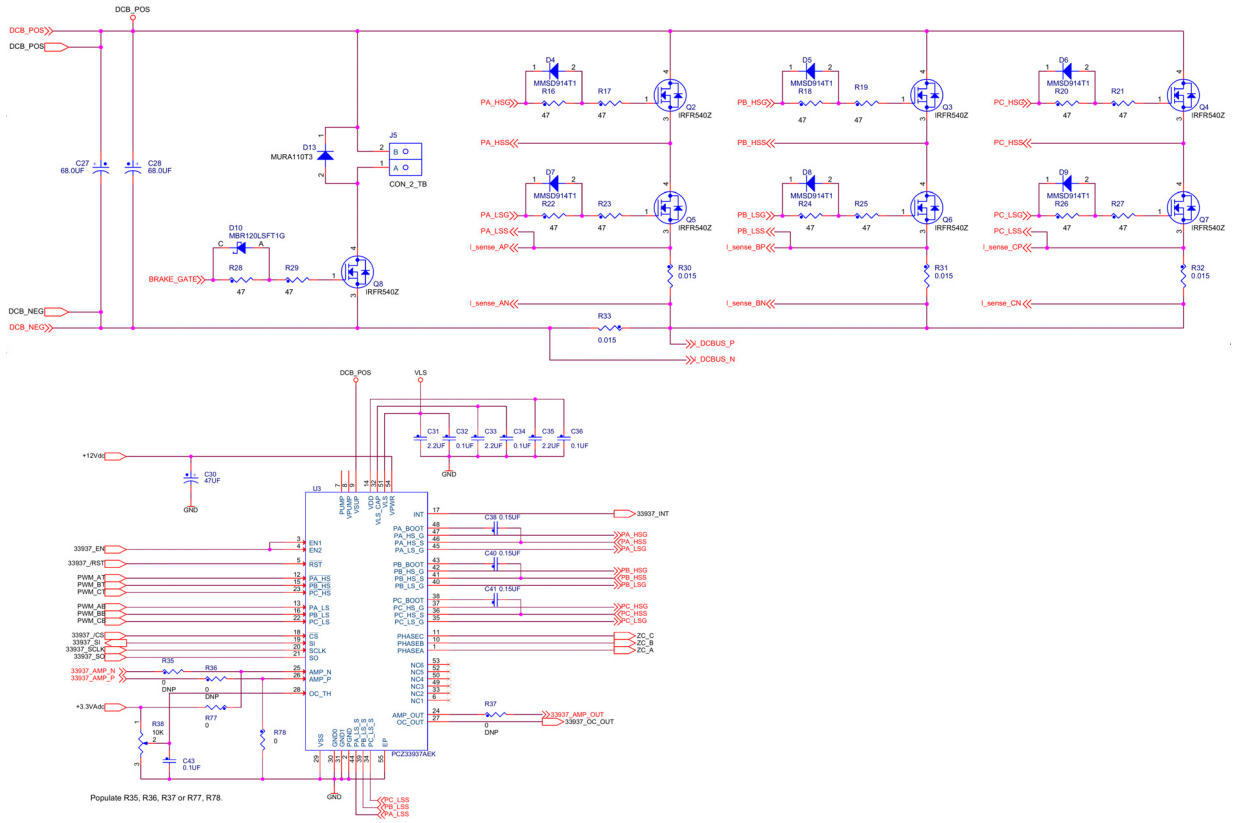

Figure 1-2. 3-phase BLDC/PMSM low voltage power stage block location

Chapter 2 Interface Description

Inputs and outputs are located on eight connectors and headers available on the board:

- Two power supply connectors J1 and J2
- Three-pin motor connector (J6, J7, J8)
- Two-pin brake connector J5
- 40-pin UNI3 connector J3
- 10-pin MC33937 interface connector J4

Pin descriptions for each connector and header are identified in the following information. Table 2-1 shows the pin assignments and signal descriptions for the UNI3 interface connector J3.

The 3-Phase BLDC/PMSM Low Voltage Power Stage contains several connectors and headers that serve for connecting the power supply for motor phases connections, and other functions.

The input power supply, attached to inputs J1 and J2, must be in the range 8 V–50 V DC.

The output for the motor is executed by the connectors J6, J7, and J8. For more details see Section 2.4, "Motor connector J6, J7, J8."

Each connector and header is labelled on the top side of the board.

2.1 Power Supply J1 and J2

The 3-Phase BLDC/PMSM Low Voltage Power Stage board can be supplied by either using the 2.1 mm DC power plug J2 or connector (J1).

The board provides 12 V, 5 V, and 3.3 V for board logic and analogue circuits, and for controllers boards connected through UNI-3 interface.

The board is designed to operate in the voltage range from 8 V–50 V. The board is protected against a reverse battery.

2.2 UNI3 Interface J3

The Unified Interface Version 3 (UNI-3) defines the interface between the 3-Phase BLDC/PMSM Low Voltage Power Stage and the dedicated controller board.

The list of UNI-3 signals is as follows:

- Control signals:
  - PWM phase A, B, C top and bottom switches control
  - Braking chopper control signal
  - Power Factor Correction (PFC)
- Monitor signals
  - DC-bus voltage
  - DC-bus current

  - Phase A, B, C current
  - Zero-cross signals
  - Back-EMF phase A, B, C
  - Temperature monitoring
- Power Supply 12 V
- Serial line — A bidirectional communication line between the Controller Board and Power Stage

Table 2-1 defines the UNI-3 pin-out.

Table 2-1. UNI-3 signal description

Interface Pin	Signal Name	MCU Signal	Description	Direction
1	PWM_AT	–	Phase A top switch control (H -> Turn OFF)	Digital input
3	PWM_AB	–	Phase A bottom switch control (H -> Turn ON)	Digital input
5	PWM_BT	–	Phase B top switch control (H -> Turn OFF)	Digital input
7	PWM_BB	–	Phase B bottom switch control (H -> Turn ON)	Digital input
9	PWM_CT	–	Phase C top switch control (H -> Turn OFF)	Digital input
11	PWM_CB	–	Phase C bottom switch control (H -> Turn ON)	Digital input
2, 4, 6, 8, 10	Shield	–	PWM signals shield (grounded on the power stage side only)	–
12,13	GND_D	–	Digital power supply ground	–
14, 15	+5 V DC	–	+5 V digital power supply	–
17, 18	AGND	–	Analog power supply ground	–
19	+12/+15 V DC	–	Analog power supply	–
16,20, 27, 28,37	NC	–	Not connected	–
21	V_{DCBUS}	–	DC-bus voltage sensing, 0 V – 3.3 V	Analog output
22	I_{DCBUS}	–	DC-bus current sensing, 0V – 3.3V	Analog output
23 24 25	I_A I_B I_C	–	Phase A current sensing, 0 – 3.3 V Phase B current sensing, 0 – 3.3 V Phase C current sensing, 0 – 3.3 V	Analog output
26	TEMP	–	Analog temperature 0 V – 3.3 V	Analog output
29	BRAKE_CONT	–	DC-bus brake control	Digital input
30	SERIAL	–	Serial interface	Dig. bidirectional
31	PFC	–	Power factor correction PWM	Digital input
32	PFCEN	–	Power factor correction enable	Digital input
33	PFCZC	–	Power factor correction Zero-cross	Digital output
34	ZCA	–	Phase A Back-EMF zero crossing	Digital output
35	ZCB	–	Phase B Back-EMF zero crossing	Digital output
36	ZCC	–	Phase C Back-EMF zero crossing	Digital output

Table 2-1. UNI-3 signal description (continued)

Interface Pin	Signal Name	MCU Signal	Description	Direction
38	Back-EMF_A	–	Phase A Back-EMF voltage sensing	Analog output
39	Back-EMF_B	PAD2	Phase B Back-EMF voltage sensing	Analog output
40	Back-EMF_C	PAD4	Phase C Back-EMF voltage sensing	Analog output

2.3 MC33937A Interface J4

The phase top and bottom switches are controlled by the MC33937A pre-driver. The device is configured by the SPI, see Table 2-2.

Table 2-2. MC33937A signal description

Interface Pin	Signal Name	MCU Signal	Description	Direction
1	NC	–	Not connected	–
2	NC	–	Not connected	–
3	MC33937_EN	–	Device enable	Digital input
4	MC33937_OC	–	Over current. Totem pole digital output of overcurrent comparator	Digital output
5	MC33937_/RST	–	Reset input	Digital input
6	MC33937_INT	–	Interrupt pin output	Digital output
7	MC33937_SOUT	–	Output data for SPI port. Tri-state until $\overline{CS}$ becomes low	Digital output
8	MC33937_SCK	–	Clock for the SPI port	Digital input
9	MC33937_CS	–	Chip select input. It frames the SPI command and enables the SPI port	Digital input
10	MC33937_SIN	–	Input data for the SPI port. Clocked on the falling edge of SCLK, MSB first	Digital input

2.4 Motor connector J6, J7, J8

Power outputs to the motor are located on connectors J6, J7, and J8. Phase outputs are labelled A, B, and C. A permanent magnet synchronous or brushless DC motor phase windings can be connected to the connectors J6, J7, and J8. Table 2-3 contains pin assignments.

Table 2-3. Motor Connector — signal description

Pin	Signal name	Description
J6	Phase A	Supplies power to motor phase A
J7	Phase B	Supplies power to motor phase B
J8	Phase C	Supplies power to motor phase C

2.5 Braking chopper connector J5

The braking resistor can be joined to connector J5. This is located on the left top corner of the board.

Table 2-4. Brake resistor connector — signal description

Pin	Signal name	Description
1	– Brake_res	Brake resistor negative terminal
2	+ Brake_res	Brake resistor positive terminal

Chapter 3 Design Consideration

The 3-phase BLDC/PMSM low voltage power stage demonstrates the ability of Freescale microcontrollers and DSCs to control various electrical motors and for easy SW development. In addition to the hardware needed to run a motor, a variety of feedback signals that facilitate control-algorithm development are provided. A set of schematics for the drive is explained in the following section.

3.1 3-phase power bridge

The power stage is configured as a 3-phase power bridge with MOSFET output transistors. It is simplified considerably by an integrated gate driver that has several safety features. Figure 3-1 shows a schematic of the 3-phase power bridge. The pre-driver inputs are 3.3 V compatible. A Freescale MC33937 pre-driver provides a supply voltage for the low and high side MOSFET gates. The MC33937 also provides the MOSFETs and application protection. It integrates an under voltage hold-off, desaturation, phase comparators, and over-current protection circuits. The dead time insertion can be configured using SPI. The default dead time value is typically 15 us. The low and high side drivers are capable of providing a typical current of 1 Amp. This gate drive current may be limited by an external resistor to achieve a good trade-off between the efficiency and EMC compliance of the application.

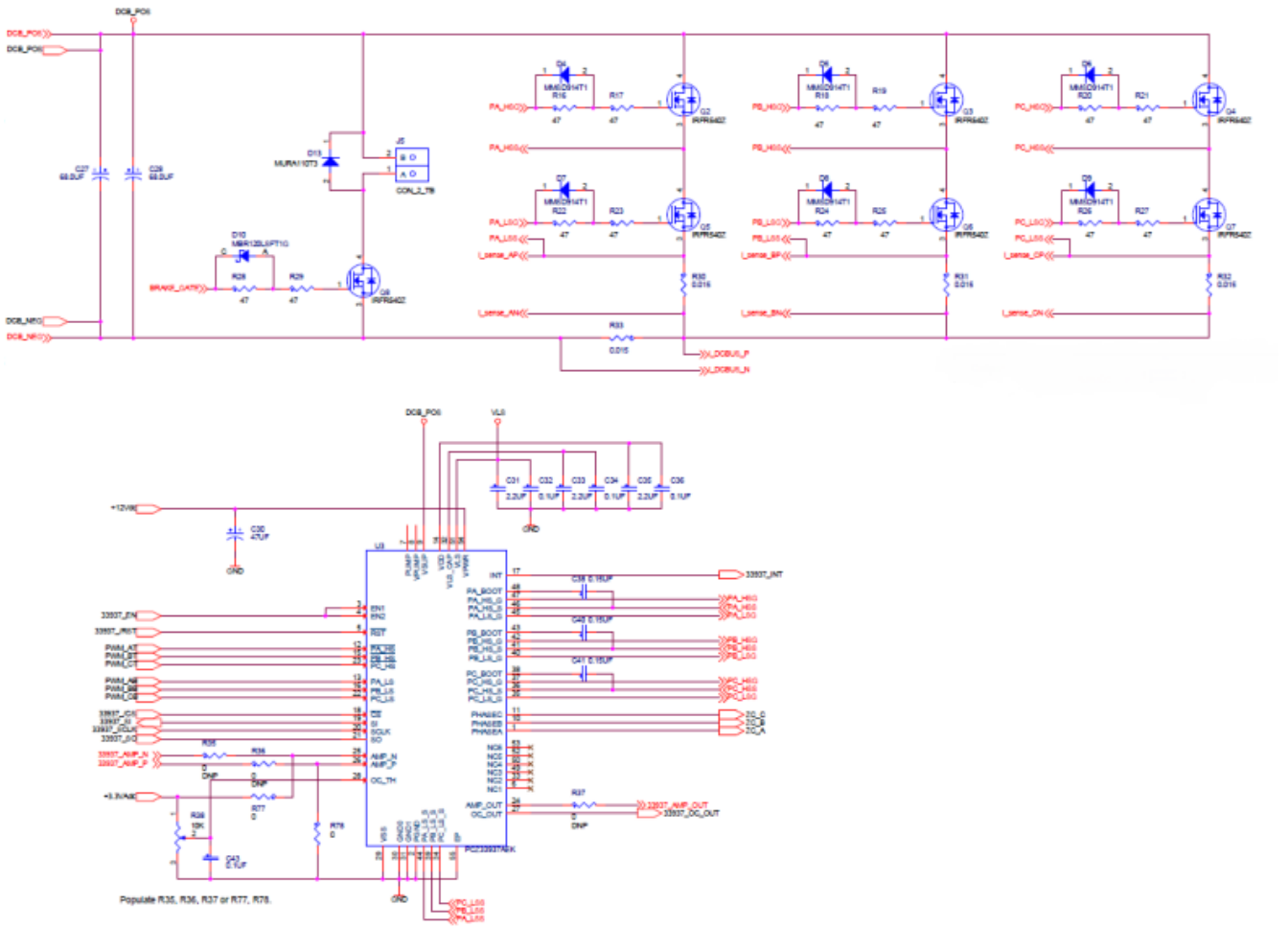

Figure 3-1. 3-phase power bridge

3.2 DC Bus voltage and current feedback

Figure 3-2 shows the circuity that provides feedback signals proportional to DC bus voltage and current. Bus voltage is scaled down by a voltage divider consisting of R40, R42. The populated resistor values are chosen in such way that a 50.05 V, 36.025 V, or 18.298 V DC bus voltage corresponds to V_{REF} at output V_DCBUS. This output signal is connected to the UNI3 connector pin 21.

Figure 4-2 shows the circuitry supporting DC bus current sensing. The DC bus current is sampled by shunt resistor R33. The voltage drop for this resistor can be amplified by either the MC33937 internal amplifier or an AD8656 operational amplifier (if populated). Both amplifiers are used as a differential amplifier for DC bus current sensing. With R46=R52, and R48=R50, the gain is given by:

$$A = \frac{R46}{R48}$$

The output voltage is shifted up by +1.65V V_{REF} to accommodate positive and negative current swings. A ±150mV voltage drop across the sense resistor corresponds to a measured current range of ±10Amps.

If you use the MC33937 for current measurement, the I_DCBUS signal is internally connected to the over current comparator, and provides an over current triggering function. A discussion about over-current limiting follows in section 3.3.

The DC bus current may be measured by an AD8656. To use this option, the zero resistors R35, R36 and R37 cannot be populated. MC33937 operational amplifier inputs must be grounded to avoid incorrect OC output behavior.

The output from opam I_DCBUS is joined to the UNI3 connector pin 22. The shunt resistor is represented by a 0.015 Ω resistance (Cyntec SMD), the same type as the phase current measurement resistors.

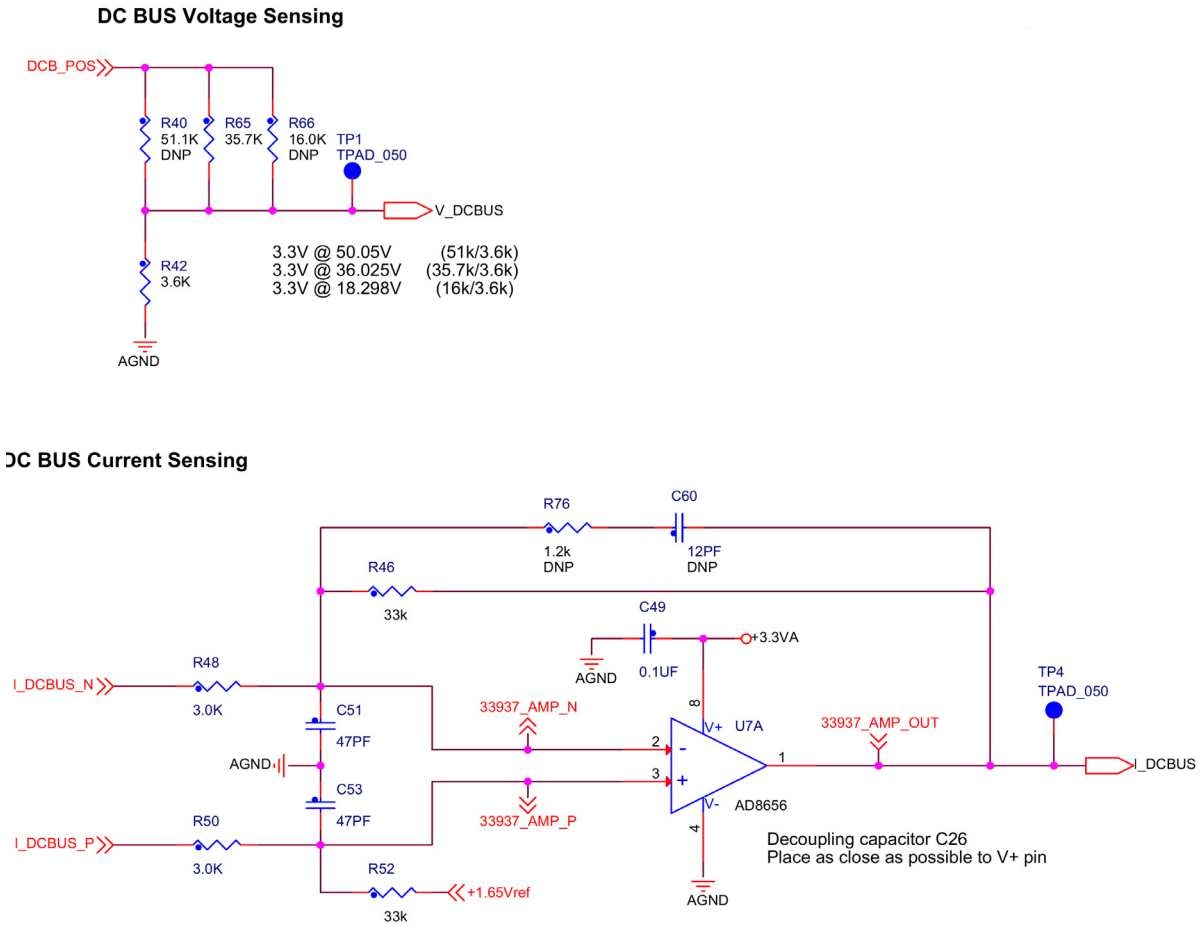

Figure 3-2. DC Bus current and voltage sensing

3.3 Over-current, under-voltage, and other safety functions

The MC33937A provides over-current and under-voltage functions. The amplified DC Bus current signal is filtered to remove spikes, and then it is internally fed into the MC33937 over-current comparator input. The OC comparator threshold level is adjusted by external trimmer R38 and filtered by C43. This signal is connected to the MC33937 pin 28 OC_TH. Therefore, when DC bus current exceeds the adjusted threshold level, all six bridge transistors are switched off. After a fault state has been detected, all six gate drivers are off, until the fault state is cleared by the SPI command or $\overline{\text{RESET}}$ pin.

The under voltage function is implemented internally. The IC guarantees that the output FETs are turned off in the absence of V_{DD} or V_{PWR} by means of the Hold-off circuit. When V_{DD} is less than about 3.0 V or V_{PWR} is lower than the typically 8.0 V, a small current source pulls all output gate drive pins low and if set an interrupt is generated.

The MC33937A safety functions keep the driver operating properly and within safety limits. It has a thermal warning feature. If the IC temperature rises above 170 °C on one of three individual thermal warning circuits, then an interrupt is generated if set. The IC has other safety functions, such as desaturation detection, phase error, framing error, write error after a lock, and exiting $\overline{\text{RESET}}$. All these features can be configured through the SPI interface to trigger interrupts.

A detailed description is available in the driver datasheet.

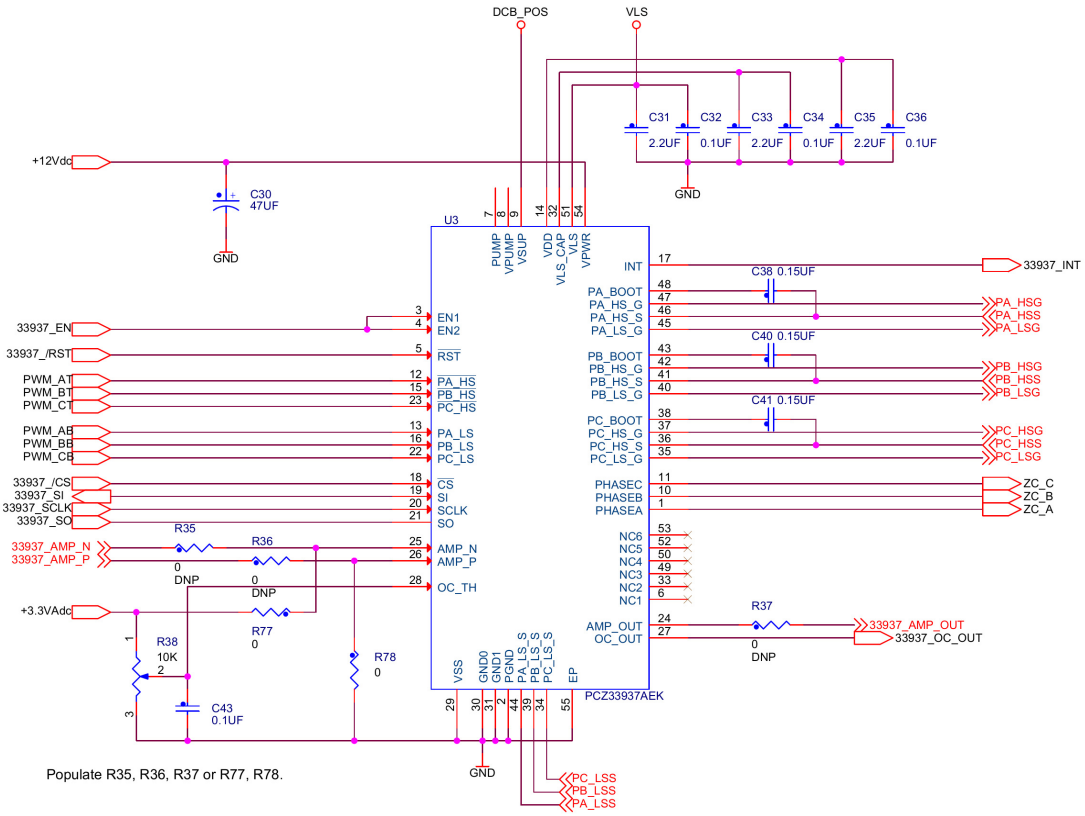

Figure 3-3. MC33937A circuit

3.4 Back EMF signals

Back EMF signals are included to support sensorless algorithms for BLDC motors, and dead time distortion correction for a sinusoidal motor. Figure 3-4 shows circuitry for phase A; the raw phase voltage is scaled down by a voltage divider consisting of R55 (R67 or R70) and R60. Output from this divider produces a a back EMF sense voltage BEMF_A. The resistor values are chosen so that a 50.05 V, 36.025 V or 18.298 V of phase voltage corresponds to a 3.3 V ADC input range. The BEMF_A, BEMF_B, BEMF_C signals are directly connected to the UNI3 interface pins 38, 39, 40.

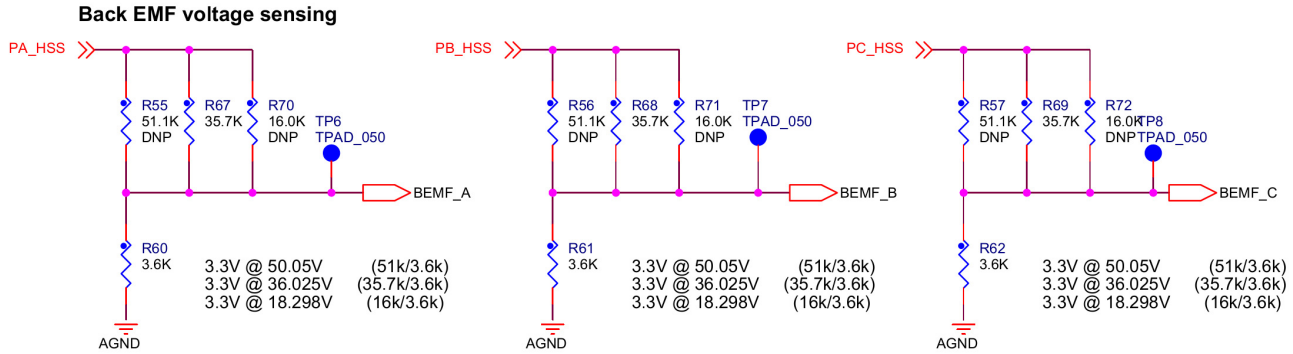

Figure 3-4. Back EMF Sensing — Phase A, B, C

3.5 Phase current sensing

Phase currents are sampled by sensing resistors R30, R31, R32 in Figure 3-5, and amplified in the U5, U6 (AD8656) operational amplifiers. All amplifiers are used as a differential for phase current sensing. With R41=R43, R39=R44, the gain is given by:

$$A = \frac{R39}{R41}$$

The gain of these operational amplifiers are 11 with a +1.65 V offset. The output voltage is shifted up by +1.65 V V_{REF} to accommodate positive and negative current swings. A ±150 mV voltage drop across the sense resistor corresponds to a measured current range of ±10Amps.

The outputs from opams I_A, I_B, I_C are connected to the UNI3 connector pins 23, 24, 25 through RC filters R13, C24. The shunt resistor is represented by a 0.015 resistance (Cyntec SMD), the same shunt resistor is used for DC bus current measurement.

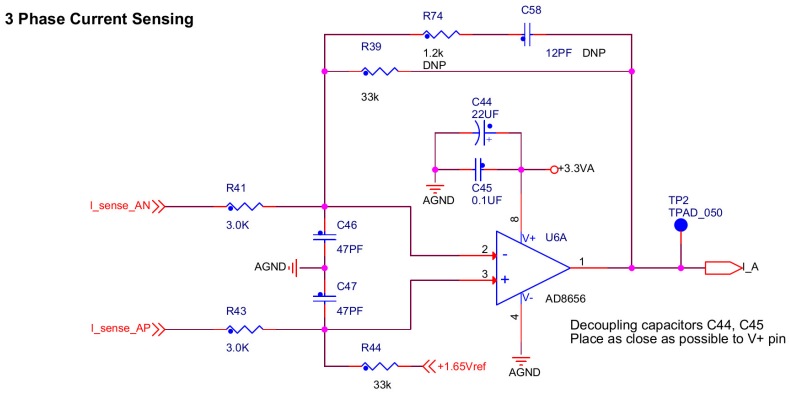

Figure 3-5. Phase current sensing circuit

3.6 Power supplies and voltage reference

The 3-phase BLDC/PMSM low voltage power stage contains devices that require various voltage levels of +12 V, +5 V, and +3.3 V.

3.6.1 Input power supply

The DC bus can be supplied from two input connectors, J1 and J2. The DC bus has reverse polarity protection. The MC33937 driver is supplied from a SEPIC DC/DC converter that delivers a constant output voltage of +12 V across the entire input voltage range (+8 V to +50 V). The +5 V and +3.3 V power supplies are taken from +12 V source.

3.6.2 +12 V power supply

The constant +12 V supply voltage for the wide input voltage range (6 V to 50 V) is provided by the SEPIC converter. This topology delivers a constant output voltage when the input voltage is below or above the

nominal output voltage. It is suitable for this input voltage range. The LM5022 is a high voltage low side N-channel MOSFET controller. The output voltage regulation is based on current-mode control. It includes a start-up regulator that operates over a wide input range of 6 V to 60V, an error amplifier, precision reference, line under-voltage lockout, cycle-by-cycle current limit, slope compensation, soft-start, external synchronization capability, and thermal shutdown. The switching frequency has been setup to 500 kHz.

3.6.3 +5 V power supply

The +5 V voltage level is generated by the step down DC/DC converter LM2694. This circuit delivers up to 600 mA peak output current. The switching frequency is adjusted to 500 kHz. More information is available in the converter datasheet.

3.6.4 +3.3 V power supply

An important voltage level for this board is +3.3 V. This is obtained from the MC33269D linear voltage regulator, which is able to deliver up to 800 mA. The +3.3 V level is used to supply the on-board analogue devices.

3.6.5 +1.65 V voltage reference

The +1.65 V reference is generated from the +3.3 V level by a resistors divider and an impedance isolator. This reference shifts all current sensing output signals by 1.65 V.

3.7 Brake choppper circuit

The brake chopper circuit is included to control the operation of losing the energy from the motor through regenerative braking to an external brake resistor.

There is only a power switch with a pre-driver and a freewheeling diode populated on the board. An external brake resistor must connected through the two pin connector J5.

Chapter 4 Electrical Characteristics

The electrical characteristics in Table 4-1 apply to an operation at 25 °C.

Table 4-1. Electrical Characteristics

Characteristic	Symbol	Minimum	Type	Maximum	Units
Power supply Voltage	V_{DC}	8	12, 24, 42	58	V
Quiescent Current(1)	I_{CC}	–	TBD	–	mA
Min Logic 1 Input Voltage	V_{IH}	–	–	–	mA
Max Logic 0 Input Voltage	V_{IL}	–	–	–	mA
Input Logic Resistance	R_{IN}	–	4.7	–	kΩ
Analogue Output Range	V_{OUT}	0	-	3.3	V
Bus Current Sense Voltage	V_{ISNS}	–	165	–	mV/A
Bus Current Sense Offset	$V_{ISNSOFF}$	–	1.65	–	V
Bus Voltage Sense Voltage: ..... 12 V range 24 V range 48 V range	V_{BUS}	5.3564 10.7203 14.8861	5.4445 10.9167 15.1667	5.5342 11.117 15.4529	V/V
Phase A, B, C Current Sense Voltage	V_{IASNS}	–	165	–	mV/A
Phase A, B, C Current Sense Offset	$V_{IASNSOFF}$	–	1.65	–	V
Power MOSFET On Resistance	$R_{DS(ON)}$	–	22.5	28.5	mΩ
Continuous Output Current, T_C =25 °C	I_D	–	35	–	A
Pulsed Output Current	I_{DM}	–	140	–	A
Total Power Dissipation (per MOSFET)(2)	P_D	–	TBD	–	W
Required Deadtime	t_{OFF}	–	77	–	ns

1—measured at 12 V power supply

2—The values are measured at 25 °C. Values may differ for other temperatures.

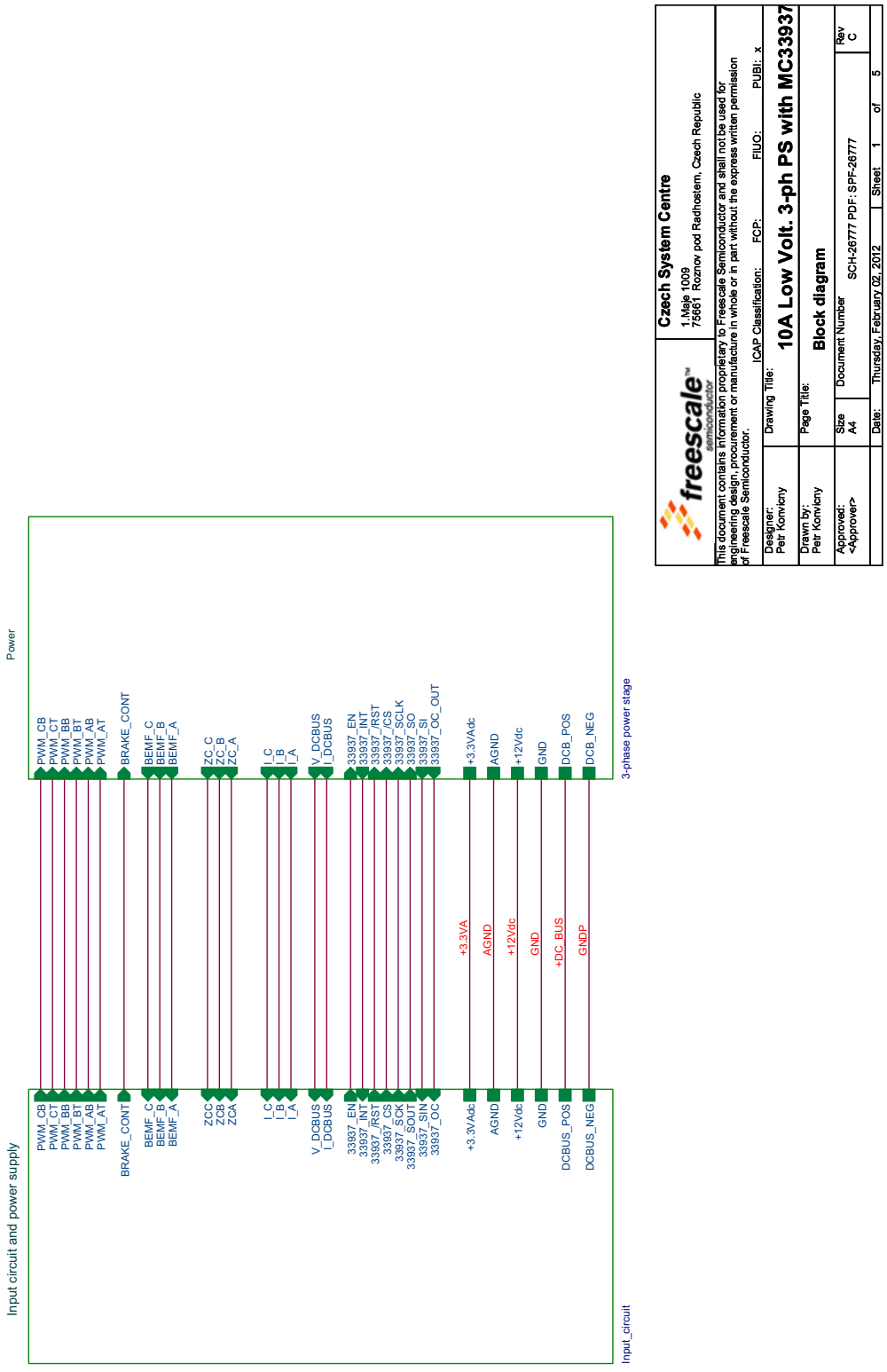

Figure 4-1. Schematic — Block diagram

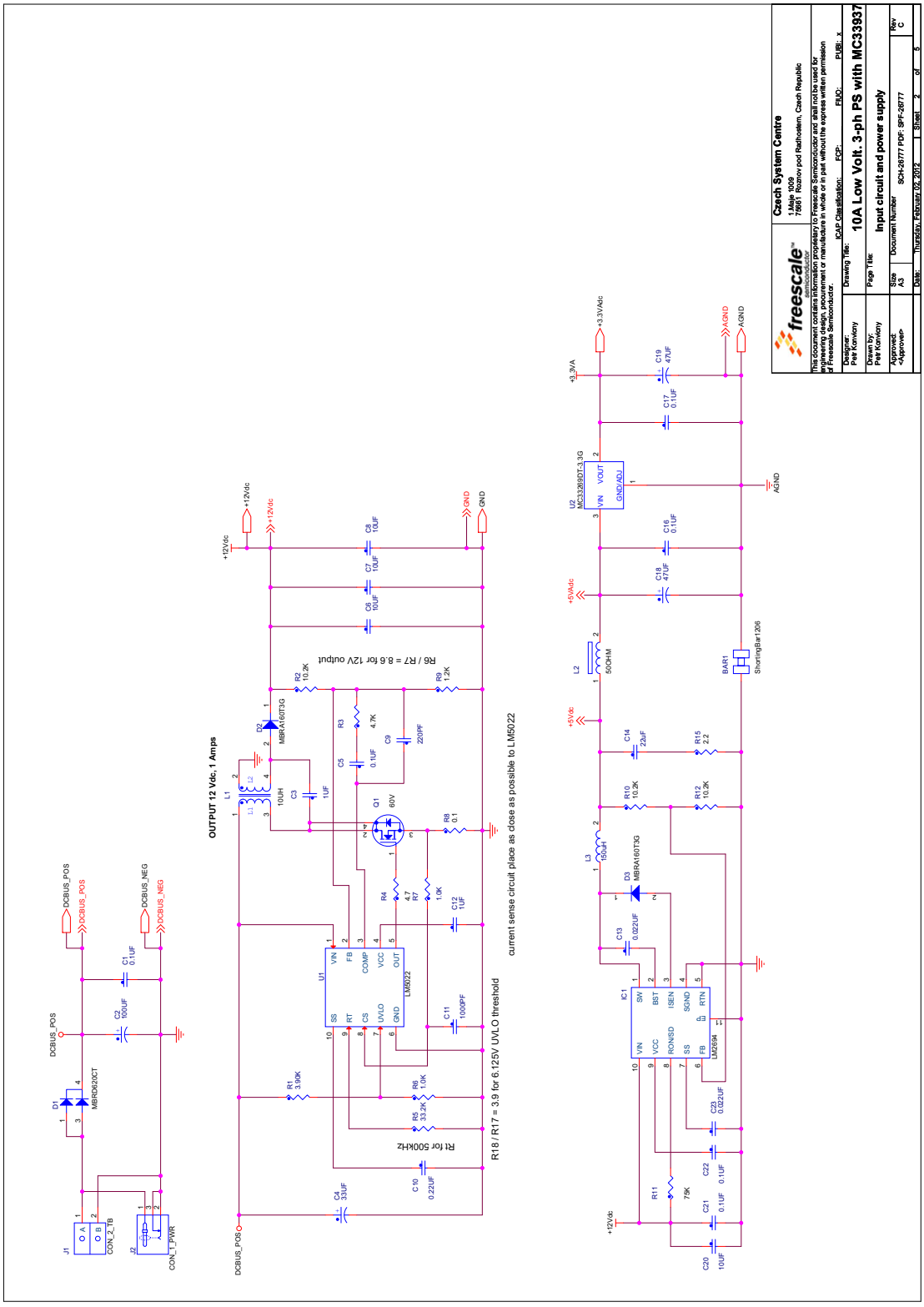

Figure 4-2. Schematic -— Input circuit and power supply

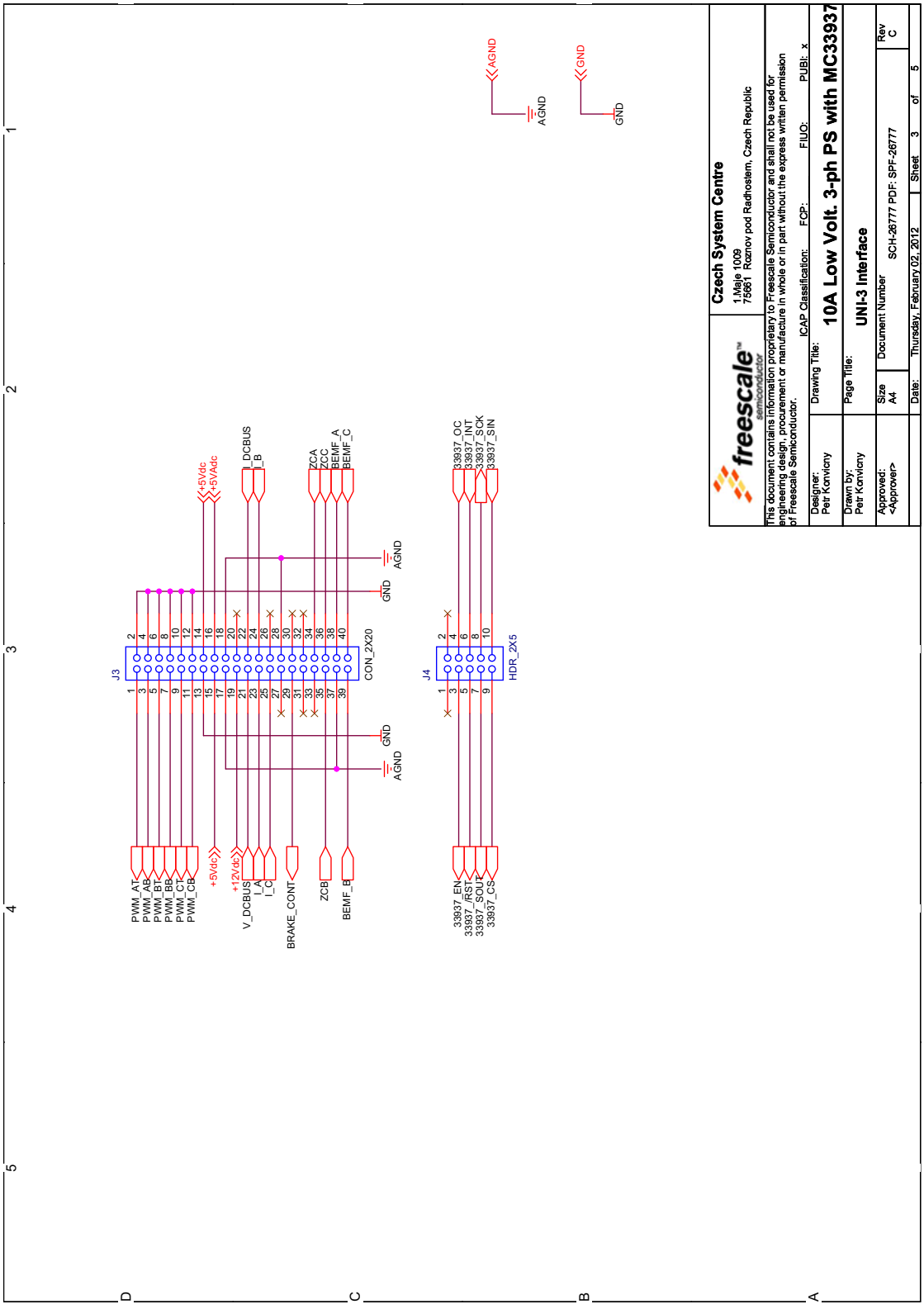

Figure 4-3. Schematic — UNI-3 Interface

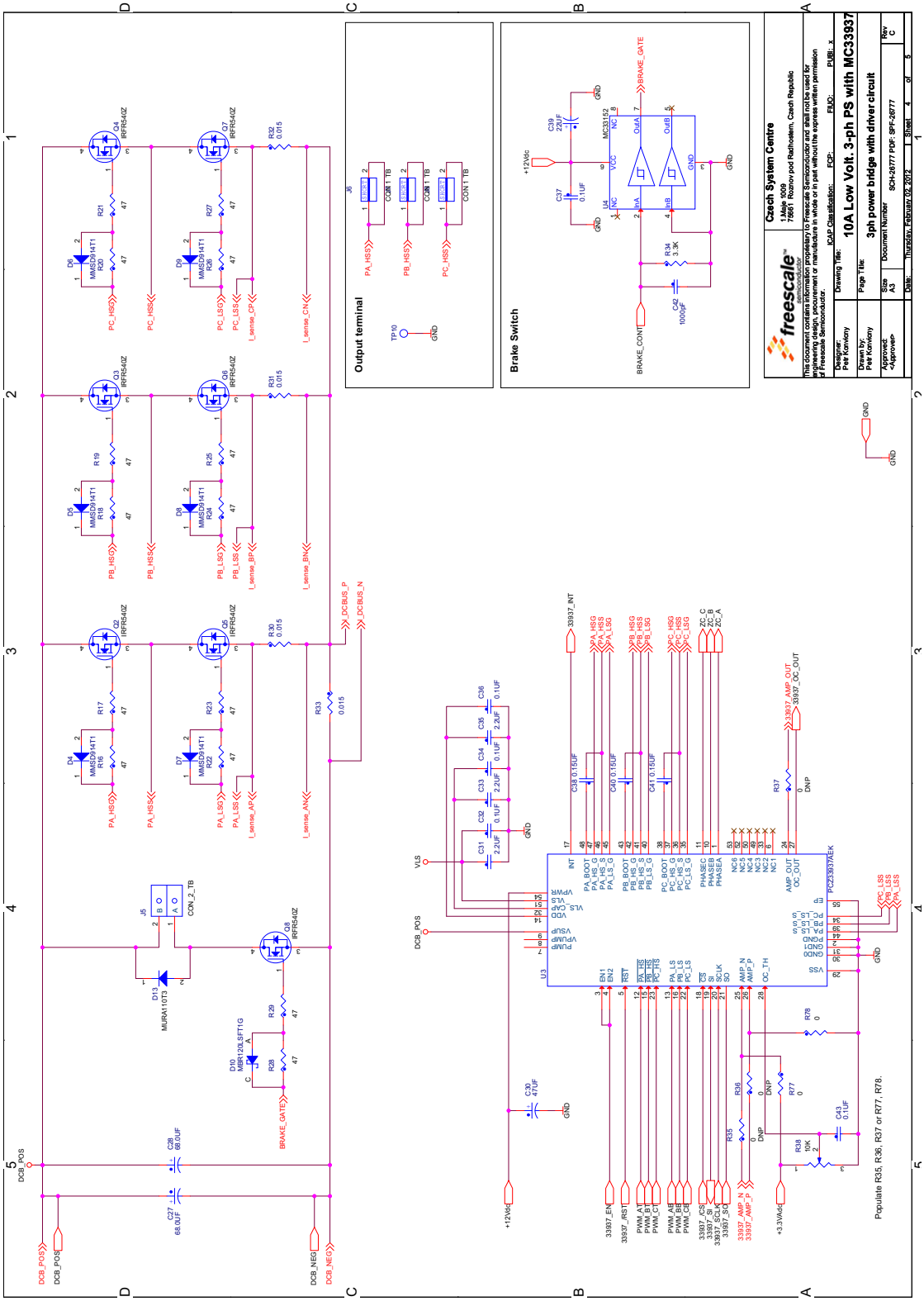
Czech System Centre
10A Low Volt. 3-ph PS with MC33937
3ph power bridge with driver circuit
Output terminal
Brake Switch
Populate R35, R36, R37 or R77, R78.

Figure 4-4. Schematic — 3ph power bridge with driver circuit

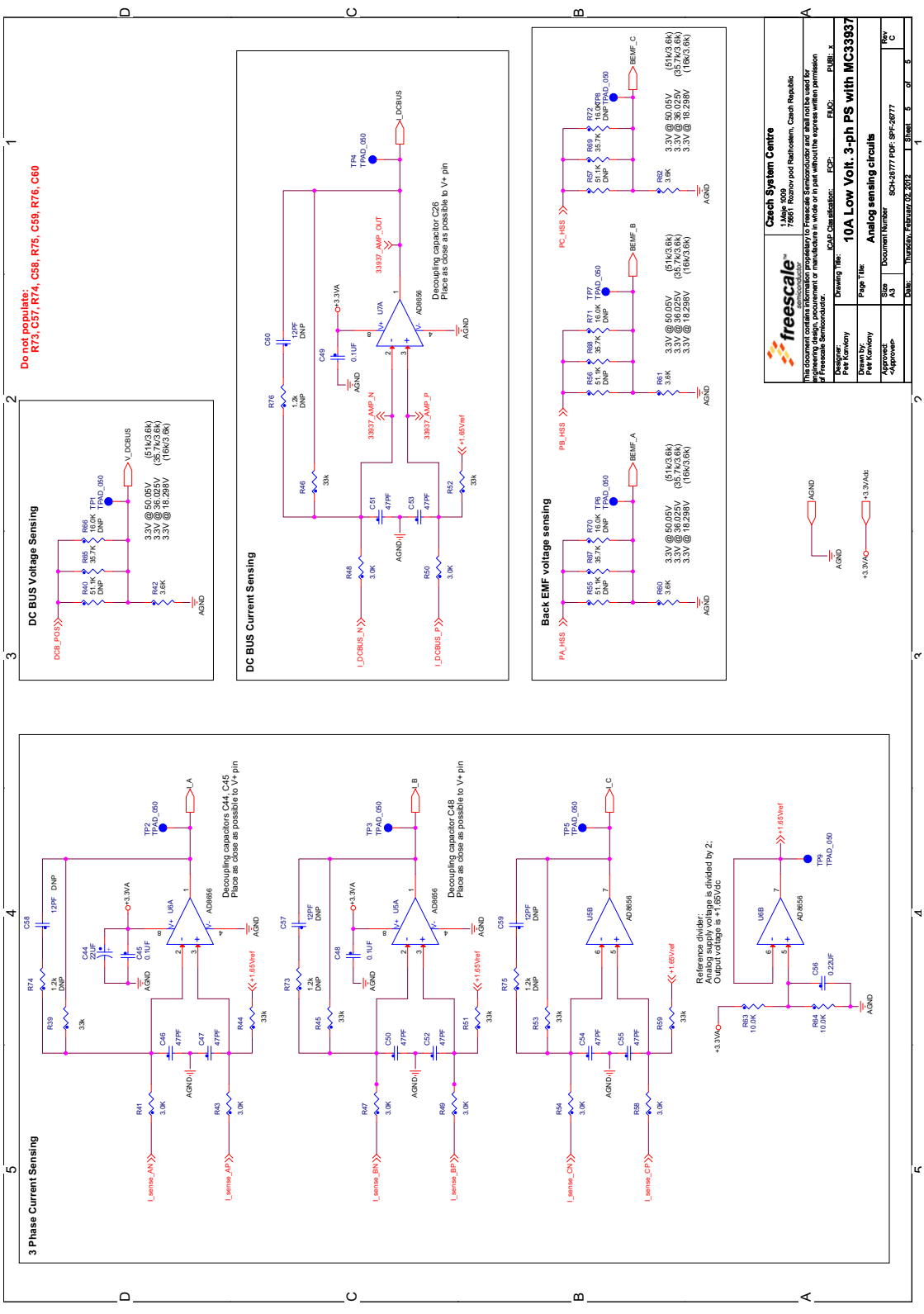
Do not populate:
R73, C57, R74, C58, R75, C59, R76, C60
DC BUS Voltage Sensing
DC BUS Current Sensing
Back EMF voltage sensing
3 Phase Current Sensing
Decoupling capacitor C26
Place as close as possible to V+ pin
Decoupling capacitors C44, C45
Place as close as possible to V+ pin
Decoupling capacitor C48
Place as close as possible to V+ pin
Reference divider:
Analog supply voltage is divided by 2;
Output voltage is +1.65Vdc
Czech System Centre
Analog sensing circuits
10A Low Volt. 3-ph PS with MC33937
SCH-28777 PDF: SPF-28777

Figure 4-5. Schematic — Analogue sensing circuits

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